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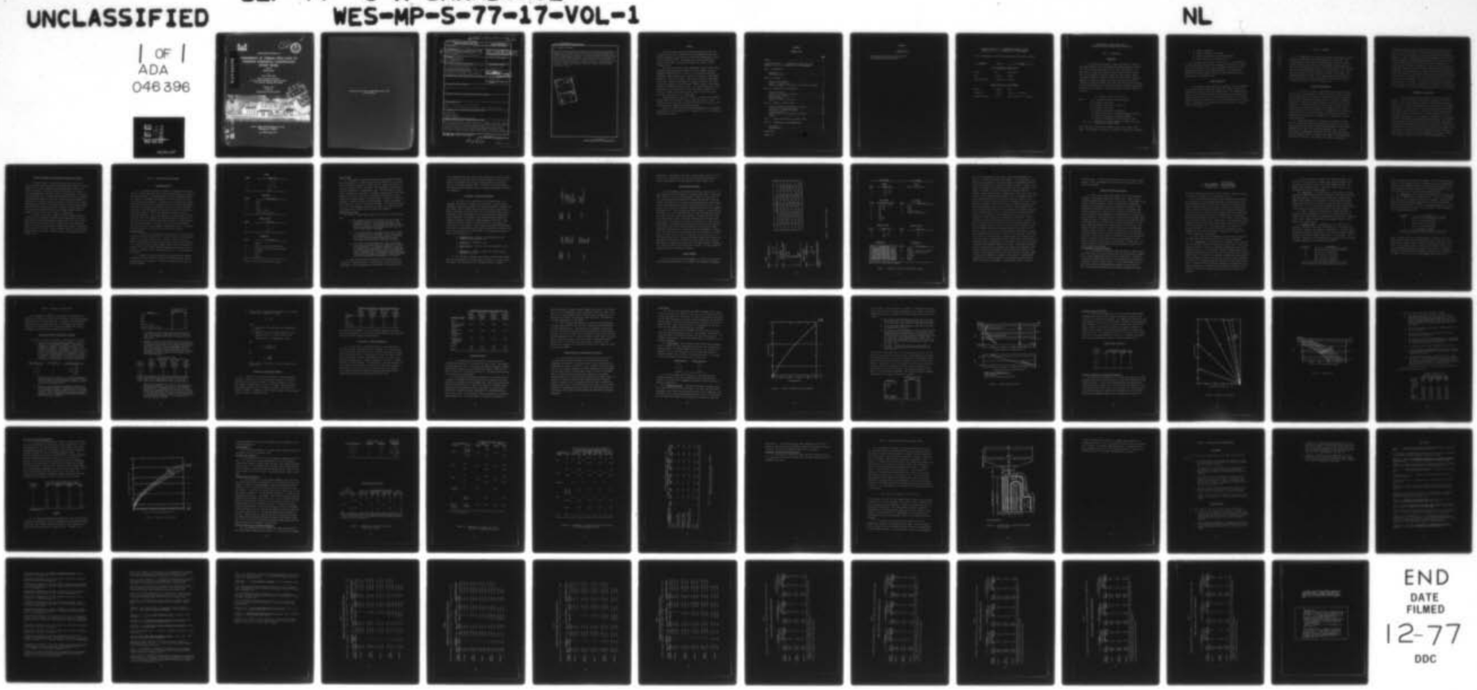

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ASSESSMENT OF TERRAIN INPUT DATA TO ENGINEER HORIZONTAL CONSTRUCTION EFFORT MODEL

Volume I

MAIN TEXT

by

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This study was conducted to assess the impact of terrain on horizontal construction in Army Facilities Components System's four climatic zones. This included the identification of terrain conditions in selected countries within each zone and the evaluation of terrain effect variables used as input to the Engineer Horizontal Construction Effort Model (EHCEM). This model estimates the number of engineer battalion-days to construct specific types of airfields. over

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20. ABSTRACT (Continued)

The present terrain input data were analyzed and the difficulty and volume indexes used in the EHCEM were evaluated. The revised data were applied to the selected terrain condition countries. Terrain conditions were mapped in 20 countries within the four climatic zones by using available data and applying state-of-the-art mapping procedures. The terrain arrays were correlated with the volume and difficulty indexes. These data were used to identify the revisions required to improve the output of the EHCEM. The frequency and areal coverage of each unique terrain configuration array were determined and a statistical analysis was performed on terrain conditions that occur within each climatic zone.

PREFACE

The study reported herein was conducted during February 1976 through July 1977 under the Army Facilities Components System (AFCS) Project 1975-1977 for the Director of Facilities Engineering, Office, Chief of Engineers (OCE). This study was a terrain assessment to correlate its impact on horizontal construction within four AFCS climatic zones.

The work was performed in the Terrestrial Sciences Branch (TSB), Engineering Geology and Rock Mechanics Division (EGRMD), Soils and Pavements Laboratory (S&PL), of the U. S. Army Engineer Waterways Experiment Station (WES), by Mrs. Marilyn B. Worthy, SP5 David Hyman, and Messrs. Jerald D. Broughton, John R. May, and John H. Shamburger, Chief, TSB. Computer programming for storage, retrieval, and calculational procedures was performed by Mr. Arden P. Parks, Soils Testing Branch, Soil Mechanics Division, S&PL. The study was under the direct supervision of Mr. Shamburger and under the general supervision of Mr. Don C. Banks, Chief, EGRMD, and Mr. James P. Sale, Chief, S&PL. This report was written by Mr. Shamburger.

Acknowledgement is made to Mr. Sidney G. Tucker, Chief, Membrane Branch, Materiel Development Division, S&PL, MAJ Steven F. Rutz, formerly with the S&PL, and Mr. Robert Elliston and Mr. Rex Giles, OCE, for their helpful suggestions during the study.

Directors of WES during the study and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Mr. F. R. Brown was the Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) AND METRIC (SI) TO U. S. CUSTOMARY UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
U. S. Customary to Metric (SI)		
inches	25.4	millimetres
feet	0.3048	metres
degrees (angle)	0.01745329	radians
Metric (SI) to U. S. Customary		
metres	3.28084	feet
kilometres	0.621371	miles (U. S. statute)
square kilometres	0.386	square miles (U. S. statute)

ASSESSMENT OF TERRAIN INPUT DATA TO ENGINEER HORIZONTAL CONSTRUCTION EFFORT MODEL

PART I: INTRODUCTION

Background

1. This study was conducted to assess the impact of terrain on horizontal construction in Army Facilities Components System's (AFCS) four climatic zones (temperate, frigid, tropic, and desert). The assessment of terrain was limited to those factors that are used as input to the Engineer Horizontal Construction Effort Model (EHCEM). The EHCEM estimates the amount of effort in battalion-days required to construct a runway or helipad. This model uses values for various variables and constants selected for input which are dependent upon the terrain characteristics at a site and the type of airfield (operational category) to be constructed. The basic construction effort equation is as follows:

$$C_e = \{k_g(V_sD_s + V_rD_r) + k_dd + k_cC\} F$$

where

C_e = construction effort (in battalion-days)

V_s = volume of soil moved

D_s = relative difficulty of moving soil

V_r = volume of rock moved

D_r = relative difficulty of moving rock

d = relative difficulty of providing adequate drainage

C = relative difficulty of clearing vegetation

F = factor corresponding to type of battalion used

k_g, k_d, k_c = appropriate constants based on aircraft load, tire pressure, and runway length

This study did not include any analysis of the k or F input to the model. The influence of terrain on the model is through four variables:

a. Volume of grading.

b. Relative difficulty of grading.

c. Relative difficulty of providing drainage.

d. Effort involved in clearing the site.

2. The model was developed in 1962 at the U. S. Army Engineer Waterways Experiment Station (WES) and applied extensively in a number of top level Army and Office, Chief of Engineers construction effort analyses applications in the 1962-1968 period. A more detailed description of input variables and their relationship with terrain characteristics is presented later.

Purpose and Scope

3. The purpose of this study was to perform a terrain assessment to correlate terrain characteristics and their impact on horizontal construction within the four AFCS climatic zones. The terrain assessment involved evaluating the terrain descriptors and re-examining the degree of effects on the volume and difficulty index values. Terrain characteristics were generated for 20 countries within the four climatic zones to determine those characteristics that would have to be dealt with in each climatic zone.

PART II: APPROACH

4. The approach was to analyze the present terrain input data and evaluate the difficulty and volume indexes used in the EHCEM. The revised data were applied to the selected terrain condition countries. Terrain conditions were mapped by using available data and applying state-of-the-art mapping procedures. The terrain arrays were correlated with the volume and difficulty indexes. These data were used to identify the revisions required to improve the output of the EHCEM. The frequency and areal coverage of each unique terrain configuration array were determined and a statistical analysis was performed on terrain conditions that occur within each climatic zone.

Terrain Input Analysis

5. The initial step was to analyze the terrain factors presently used as input to the EHCEM and to identify additional terrain descriptors and index revisions necessary to improve the output of the EHCEM. This analysis was made and descriptors needed to improve the EHCEM to provide a more definitive characterization of terrain conditions were identified. Terrain descriptors used before this study were broad and provided only a generalized analysis that frequently did not sufficiently describe the actual conditions. Consequently, these generalizations detract from the input and reduce the reliability of the construction effort generated by the EHCEM for the construction of horizontal facilities.

6. Terrain parameters were scrutinized on the basis of their effects on horizontal construction and the availability of such data from published sources and/or interpretation processes. After terrain parameters (soil type, soil thickness, vegetation, etc.) had been established, each parameter was subdivided into classes (descriptive terms or ranges of values) according to the degree to which they affect horizontal construction. For example, soil types were expanded to

include map classes of gravel, sand, gravel and sand with fines, silt, clay, etc., as identified by the Unified Soil Classification System which is based on the behavior of soil as an engineering construction material. A similar analysis was made for meaningful classes for other terrain parameters. Vegetation was identified in terms of stem sizes and stem spacing needed for estimates of the effort required for clearing during horizontal construction. Before the final selection or established degree of resolution for the terrain factor classes was established, the availability of data was researched and the sources of these data identified. The degree of resolution established within data sources had to be compatible with the final classes selected for the terrain input to the EHCEM. In other words, the classes should not be too general nor too specific. The present state-of-the-art interpretation procedure of remotely sensed data was considered as a data source for this study; however, the time and area involved made it impractical.

Analysis of Index Values

7. Critical components of the EHCEM are volume and difficulty indexes. These indexes were established by determining one or the results of two terrain parameters which are considered simultaneously and the effects produced are expressed as an index number. For example, combinations of slope classes are used to determine the volume index; the relative rock volume index is identified as relationships between soil type and depth to bedrock, etc. With the addition of terrain parameters and revision of class ranges, the interaction and resulting values were reevaluated and revised indexes established. These indexes were established through existing data and by contacting appropriate sources that have experience in horizontal construction. Because of the critical part these index values play in the output of the EHCEM, these indexes had to be established after an analysis of many iterations of terrain factor associations used to determine index values. Through this analysis, revised and new index values were established.

Selection, Mapping, and Analysis of Data Base Countries

8. The next step after establishing the index values was to select data base countries, construct terrain maps utilizing the revised classes of the terrain parameters, and determine the occurrence of terrain conditions. Data base countries were selected to include as wide a representation as possible within a minimum number of countries in each climatic zone. The map preparation was originally envisioned as a minimum effort because of the world coverage previously mapped for other projects at WES; however, the revision of terrain factor classes necessitated construction of new factor maps because previously mapped countries did not have the same factor classes. The factor maps for each country were synthesized into factor complex maps (a map that portrays all four terrain factor maps on a single base).

9. Frequency and areal occupancy of factor complex patches (an outlined area on a map where specific terrain characteristics occur) were determined through measuring each patch area of all unique factor complexes for the countries within a climatic zone and counting the number of patches that represented a unique factor complex to determine the frequency of occurrence. These data were analyzed to determine the terrain conditions that were dominant, median, and subordinate in the climatic zones.

PART III: TERRAIN FACTOR ASSESSMENT

Literature Search

10. A literature search was conducted to determine the availability of terrain data that could be used as guidelines for revising the terrain descriptors. The present factors used in the EHCEM are slope, soil type, soil thickness, and vegetation. The descriptors of these factors are shown on Figure 1. The terms used to describe the terrain in available sources had to be identified so that terrain data requirements were not designed in terms that could not be readily extracted from data sources for mapping large areas of the world. Uniformity of data between areas of interest was desirable although it was not considered mandatory. Scalar considerations were a big factor for this study and small scale mapping was considered mandatory because of the area included in the data base countries that were to be mapped and the time and fund restraints. Because of the last constraint, terrain factors generated for remote imagery interpretation were not considered although this data source should be included where feasible.

Sources of data

11. The search for terrain data was conducted at and through the Technical Information Center at WES. Similar searches for data had been performed in the past and the type of holding of major sources was known. The principal sources for terrain data are the libraries at the U. S. Geological Survey, Defense Mapping Agency, Defense Intelligence Agency, Central Intelligence Agency, Geography and Map Division of the Library of Congress, and Soil Conservation Service of the Department of Agriculture.

12. Agencies where data searches are available include Defense Documentation Center, National Technical Information Service, and the American Geological Institute. Publications reviewed are included in the Bibliography.

Slope

Class	Range (%)
1	0 - 2
2	> 2 - 10
3	> 10 - 30
4	> 30

Soil Type

Class	Description
1	Sand
2	Silt
3	Clay
4	Laterite (soft)
5	Rock or hard laterite

Depth to Rock

Class	Range (ft)
1	< 2
2	2 - 20
3	> 20

Vegetation

Class	Description
1	Barren
2	Grass or large cultivated fields
3	Savannah or small cultivated fields
4	Woodland
5	Scrub
6	Forest

Figure 1. Prestudy terrain factor classes.

Types of data

13. Data types are basically text material and maps (air photos were not considered). Content of material from either source can range from a detailed description of a small area to a generalized account of an entire country or even a continent. The descriptive terms will also vary from qualitative to quantitative terms. The data types for individual countries will also vary. For example, geologic and/or soil maps ranging in scale from 1:300,000 to 1:600,000 are available for practically all of West Germany. Geological maps at a scale of 1:25,000 are available for about 40 percent of West Germany. Complete topographic map coverage at a scale of 1:25,000 is available. In contrast, geological, soils, and topographic information in some of the other countries is available only at small scale (1:1,000,000 or smaller).

Applicability of data

14. There are three basic problems in using most existing terrain data:

a. The compiled data were not intended for use as input to mathematical models. The result is that much of the information consists of semiquantitative and/or qualitative descriptions. These descriptions must be transformed into quantitative descriptions before they can be used for data input to the EHCEM.

b. The descriptors used in the existing data are not based on the requirements of the EHCEM. As a result, many of the descriptors are not directly relevant to the EHCEM and in such cases the existing descriptors must be correlated with the factors required by the EHCEM.

c. The formats of existing data vary. While reports may cover the same subject matter, the data are not treated in the same manner. For example, vegetation studies of two adjacent areas may treat the material in unique ways and the resulting classifications may be somewhat different on adjacent maps. This makes it almost impossible to translate uniformly and consistently from the existing data to the quantitative requirements of the EHCEM.

15. Even with these basic problems of using existing data, it was the only practical course to follow because of the time and fund constraints. After identifying the basic types of data available for

world countries which also involve area coverage, scale, and the degree of generalization and the amount of effort required to translate the data to the required terms, the only practical data source was the National Intelligence Surveys (NIS). The NIS's are the only readily available and really extensive source of compiled geographic and cultural information.

Selection of Data Base Countries

16. The AFCS is to be employed in four climatic zones: (a) temperate, (b) frigid, (c) tropic, and (d) desert. This diversified employment required the selection of countries within each climatic zone to collect a body of terrain data that could be used as input to the EHCEM. These data collections also had to be performed with the goal of including as good a representation of terrain conditions within each zone as practical. The climatic zones were identified by AFCS from climatic categories identified in Army Regulation (AR) 70-38. These categories are broad classes of climate useful for consideration of their effect on AFCS designs. Seven climatic categories differentiated on the basis of temperature and/or humidity extremes are included in the zones for the purpose of the AFCS design. The categories included in each zone are listed below:

a. Temperate zone. Category 5, intermediate hot dry; Category 6, intermediate cold.

b. Frigid zone. Category 7, cold.

c. Tropical zone. Category 1, wet warm; Category 2, wet hot.

d. Desert zone. Category 3, humid, hot coastal desert; Category 4, hot dry.

17. The data base countries were selected using the above guidelines and are presented by climatic zones in Figure 2. In some instances complete countries did not fall entirely within the climatic

Climatic Region	Country	Climatic Region	Country
Tropic	Panama Thailand Nigeria Laos Cambodia	Temperate	E. Germany W. Germany S. Korea Belgium Netherlands France
Desert	Lebanon Jordan Egypt Iraq Iran Algeria	Frigid	Finland Sweden W. Siberia N 60°

Figure 2. AFCS data base countries

categories as identified in AR 70-38. This was particularly true in the desert zone. Nevertheless, the countries selected were believed to contain representative terrain conditions in each climatic zone.

Terrain Factor Analysis

18. The assumption was made that the terrain factors (slope, soil type, depth to rock, and vegetation) presently being used for the model were considered to be more than adequate. However, an improvement to the classes was believed desirable to upgrade the quality of the model output. This phase of the study involved identifying the classes based on the effects that would be exerted on horizontal construction. This was the goal; however, the degree of sophistication had to be compatible with data source. After studying the present classes of terrain factors (see Figure 1), it was determined that soil type and vegetation should be revised. The soil types were expanded to coincide with the Unified Soil Classification System, which was compatible with the data source. It was felt that vegetation should have a connotation of stem sizes and stem spacing. Although these data were not given in the terms desired in the NIS's, there were sufficient data that could be used to make reasonable interpretations to obtain an improved description of vegetation. The data source allowed dividing the soil thickness into one more class; the map class (2-20 ft) was subdivided into 2-10 and 10-20 ft. The slope classes were not changed principally because data sources were restricted to the present classes and the time that would be involved generating more detailed slope data from other sources made it impractical. Figure 3 presents the revised factor classes. The new classes are compared with the old classes on Figure 4.

Terrain Mapping

19. The first step in the development of a body of data describing terrain characteristics in the climatic zones consisted of mapping

Slope

Class	Range (%)
1	0 - 2
2	> 2 - 10
3	>10 - 30
4	>30

Soil Type

Class	Description (USCS*)
1	GW, GP, GC, GM
2	SW, SP
3	SC, SM,
4	CL
5	ML
6	CH
7	MH
8	Organic
9	Rock

Depth to Rock

Class	Range (ft)
1	< 2
2	2 - 10
3	>10 - 20
4	>20

*Unified Soil Classification System

Class	Stem Diameter (in.)				
	< 1-6	6-12	12-18	18-24	>24
1	25-50	Absent	Absent	Absent	Absent
2	10-25	25-50	Absent	Absent	Absent
3	< 10	25-50	100-200	>200	Absent
4	< 10	10-25	50-100	>200	>200
5	< 10	10-25	25-50	100-200	>200
6	25-50	10-25	10-25	50-100	100-200

Figure 3. Revised factor classes

NEW LEGEND

Slope

Class	Range (%)
1	0 - 2
2	> 2 - 10
3	>10 - 30
4	>30

Soil Type

Class	Description (USCS*)
1	GW, GP, GC, GM
2	SW, SP
3	SC, SM,
4	CL
5	ML
6	CH
7	MH
8	Organic
9	Rock

Depth to Rock

Class	Range (ft)
1	< 2
2	2 - 10
3	>10 - 20
4	>20

Vegetation

Class	Stem Diameter (in.)					
	<2-6	6-12	12-18	18-24	>24	
1	25-50	Absent	Absent	Absent	Absent	Stem Spacing (ft)
2	10-25	25-50	Absent	Absent	Absent	
3	<10	25-50	100-200	>200	Absent	
4	<10	10-25	50-100	>200	>200	
5	<10	10-25	25-50	100-200	>200	
6	25-50	10-25	10-25	50-100	100-200	

OLD LEGEND

Slope

Same as New Legend

Soil Type

Class	Description
1	Sand
2	Silt
3	Clay
4	Laterite (soft)
5	Rock or hard laterite

Depth to Rock

Class	Range (ft)
1	< 2
2	2 - 20
3	>20

Vegetation

Class	Description
1	Barren
2	Grass or large cult. fields
3	Savanna or small cult. fields
4	Woodland
5	Scrub
6	Forest

*Unified Soil Classification System

Figure 4. Comparison of terrain factor map classes

the data base countries in those terms required by the EHCEM (see Figure 3 for factors and their class ranges). The terrain maps in the NIS's which are relevant to the terrain input to the EHCEM are entitled "Soils," "Vegetation," and "Military Aspects of Relief." However, all of the NIS legends are not stated in exactly the terms required for the EHCEM. For example, a typical NIS may have vegetation map units labeled: dense evergreen forests, swamp forest, dense scrub, grass with scattered trees, and dense grass without trees. The EHCEM requires as index value derived from the stem spacing and stem diameter of all plants. Thus, the NIS map units had to be interpreted in terms of stem spacing and diameter. Since each NIS uses a somewhat different legend, this interpretation process had to be done for each individual NIS. These interpretations were, of course, guided by the background experience of the WES analysts, but the decisions were necessarily somewhat subjective. The product of the interpretation was in each case a pairing of the NIS legend with its approximate equivalent. After all necessary conversions had been made, the next step was to construct a map for each of the four factors for all the data base countries. This map was simply a graphic isolation of each area that exhibited characteristics within the previously selected factor value class of the various factors. Each of the outlined areas was identified by a number that corresponded to a map class. After all the individual factor maps for a specific country had been constructed, they were combined into a single map, which is designated a factor complex map. The procedure for compiling a factor complex map is to overlay the slope, soil type, depth to bedrock, and vegetation maps in that order. After these four maps have been superposed, all boundaries are traced onto a new base. Each area (or patch) thus delineated is characterized by an array of four numbers, identifying the factor value class of slope, soil type, depth to bedrock, and vegetation occurring in each patch, To simplify the identification of factor complexes, these arrays were computer tabulated and a number was assigned to each different array. A master

legend was then constructed for each climatic zone, listing all combinations of the class ranges for the four factors that occurred in the data base countries.

Analysis of Terrain Conditions

20. Factor complex types were analyzed for area occupancy and frequency of occurrence within each climatic zone. Input for area occupancy required that each patch on all the factor complex maps of the climatic zones be measured. This was accomplished by the physical measuring of each outlined area with an electronic digitizer. This instrument was operated by setting the map scale in the machine and tracing the outline of a specific factor complex patch and the area within the patch outline appeared on a display board on the machine in square kilometres. The measured patch was identified by country, factor complex, and area on a computer form. This process was continued until all patches within all the data base countries were measured. A computer program was written that summed the areas of each unique factor complex and sorted the factor complexes from minimum to maximum area occupancy, which resulted in a printout listing all factor complexes within a climatic zone and the area occupied by each. The frequency of occurrence of each factor complex was obtained by counting each terrain patch of the same factor complex and a list was printed out by the number of patches from minimum to maximum within a climatic zone. The computer printouts listing these data are presented in Volume II(C).

Area occupancy and frequency of occurrence of factor complexes

21. To determine on a weighted basis the types of terrain conditions that may be encountered during horizontal construction, an analysis of factor complexes was made for each climatic zone. The factor complexes were assimilated in terms of area occupancy and frequency of occurrence of factor complex patches. A third relationship was used which was termed area occupancy-patch frequency and was termed I_T. This relationship was determined for each factor complex as follows:

$$I_T = \frac{\text{No. of patches}}{\text{Total patches in a climatic zone}} \cdot \frac{\text{Area occupied by all patches}}{\text{Total area within a climatic zone}}$$

The factor complexes were sorted from the lowest to highest in terms of area, number of patches, and I_T {see Volume II (C)}.

22. Several methods of analysis were considered, but because of the complexity of the data being dealt with, the decision was made to have a relatively simple breakout that identified the minimum, first (lower) quartile, median, third (upper) quartile, and maximum factor complex in each of the three categories (area occupancy, frequency of occurrence, and I_T). When the factor complexes and corresponding data were extracted, the adjoining factor complexes were also extracted. These data are presented in Tables 1-4 for the desert, frigid, temperate, and tropic climatic zones, respectively. Although specific factor complexes have been identified in these tables, other factor complexes have a high probability of occurring and should be considered in planning exercises. By including other factor complexes, better guidance can be obtained concerning the engineer troop support that would be required for construction.

23. The tables are self-explanatory and only a brief summary is presented about each climatic zone in the following paragraphs.

24. Desert zone. The desert zone is comprised of six countries with a total area of 5,254,315 square kilometres (sq km). Within these countries a total of 260 factor complexes was mapped and these factor complexes occurred in 4,369 patches. The area occupancy of the factor complexes ranged from 1 sq km to 471,432 sq km and the number of patches ranged from 1 to 254 patches. Within the six data base countries, 162 factor complexes occurred only in any one country, 63 factor complexes occurred in two countries although not the same two countries in each case, 24 occurred in three countries although not the same three countries in each case, 11 occurred in four countries although not in the same four countries in each case, and none occurred in five or six countries.

25. Table 1 presents a terrain factor complex analysis. This table points out that factor complexes below the upper quartile are relatively infrequent in terms of the three weighing systems: frequency, areal occupancy, and I_T. One factor complex occurs in the maximum position of all rating systems.

26. Frigid zone. Two countries and a large portion of another country were used as data sources for this zone. The total area of the data base countries is 2,664,796 sq km and 89 factor complexes were mapped which occurred in 1,044 patches. The area occupied by factor complexes ranged from 22 to 734,702 sq km and the number of patches ranged from 1 to 89. Of the 89 factor complexes, only four were common to more than one country and none occurred in all three countries.

27. Table 2 presents the terrain factor complex analysis. A significant item that appears in the table is the fact that over 61 percent of the frigid terrain is characterized by three factor complexes and one factor complex is identified in the maximum position of all three of the rating systems.

28. Temperate zone. The temperate zone is composed of six countries which have a total area of 998,081 sq km. Two hundred and eight factor complexes were mapped in 6,962 patches. The area occupied by the factor complexes ranged from 1 to 103,309 sq km and the number of patches for each factor complex ranged from 1 to 333 patches. Of the 208 factor complexes, the following analysis was made of the occurrence of factor complexes in the six data base countries:

No. of FC	Occurred In
120	Any one of the six data base countries
50	Two of the six countries*
27	Three of the six countries*
8	Four of the six countries*
3	Five of the six countries*

* Not necessarily in the same countries in each case.

Table 3 presents the terrain factor analysis. The most dominant factor complex in the temperate zone is 3312 which occurs in the maximum position of all three weighing systems. The three factor complexes in the maximum category occupy 25.17 percent of the total area and occur in 10.65 percent of the total patches in the temperate zone.

29. Tropic zone. Five countries were included in the tropic zone which have a combined area of 1,664,317 sq km. A total of 3,523 patches were identified that represented 198 factor complexes. The area occupied by the factor complexes ranged from 6 to 223,239 sq km and the number of patches mapped for the factor complexes ranged from 1 to 149. The following analysis was made of the occurrence of factor complexes in the five data base countries:

No. of FC	Occurred In
124	Any one of the five data base countries
57	Two of the five countries*
11	Three of the five countries*
4	Four of the five countries*
2	All five mapped countries

* Not necessarily in the same countries in each case.

Table 4 presents the factor complex analysis. The three factor complexes in the maximum category occupy 28.6 percent of the area. There were no factor complexes that occurred in the maximum position of all three of the weighing systems. However, factor complex 1336 did occur under the maximum patches and the maximum category of I_T. An interesting fact is that nine factor complexes occupy more than 50 percent of the area of the tropic zone countries mapped {see Volume II (C)}.

PART IV: ANALYSIS OF INDEX VALUES

30. Components of EHCEM are volume index of material moved, difficulty of moving soil and/or rock, difficulty of providing drainage, and difficulty of clearing vegetation. To present the relationship of terrain factors, the resulting index or difficulty values, and the rationale for establishing these inputs to the EHCEM, the following paragraphs (31-33) have been extracted from TM 5-366.

Volume and Relative Difficulty of Grading

31. Volume and relative difficulty of grading are as follows:

a. The volume of material handled by grading is directly related to the topographic roughness. Topographic roughness is composed of at least three more or less independent variables: characteristic slope, local relief, and spacing of drainageways. Of these, characteristic slope appears to be most conservative; i.e., it is the best single parameter for describing roughness. Accordingly, this parameter was selected as the basis of estimates of grading volume. Four broad classes were selected, as illustrated in the following tabulation:

Slope Category, %	Volume Index, I_v	Associated Relief, ft
< 2	1	< 100
2 to 10	2	100 to 500
10 to 30	4	501 to 2000
> 30	8	> 2000

Estimates based on a selection of idealized situations indicated that the relative volume of materials that must be moved increases as an exponential function, as indicated in the tabulation above.

b. Because of the qualitative differences in materials of various textures, degrees of consolidation, and wetness, it is necessary to include correction factors for these variables. The following tabulation relates estimates of relative degrees of difficulty of handling materials to wetness and type of material.

Material	Grading Difficulty Index (D)	
	Dry	Wet
Sand	0.1	0.1
Silt	0.1	0.2
Clay	0.2	0.3
Laterite (soft)	0.2	0.3
Rock or laterite (hard)	1.5	1.5

For example, it can be seen that half again as much effort is required to grade wet clay as to grade dry clay, and 15 times as much effort to handle rock as to handle sand.

c. Because of the very large differences in the handling difficulty of soil versus rock, a correction factor must be included which will give a generalized value for the proportion of each in a given topographic situation. Since the characteristic slope was selected as the topographic indicator, these proportions were calculated on the basis of slope classes, as illustrated in the following tabulation.

Soil Thickness, ft	Relative Rock Volume, V_i			
	< 2% Characteristic Slope	2% to 10% Characteristic Slope	10% to 30% Characteristic Slope	> 30% Characteristic Slope
< 2	20†	40	60	90
2 to 20	10	20	50	80
> 20	0	10	30	60

† Value indicates that 20% of the graded volume will probably be rock in those areas where the soil is less than 2 feet thick and the characteristic slope is less than 2%.

However, the proportion of rock to soil in any given topographic situation is a function of the thickness of the soil layer. The thicker the soil, the lower the probability of encountering rock; the obvious corollary is that the thicker the soil, the less the total volume of rock that will have to be moved. The tabulation above is a generalized estimation of the relation and its corollary acting in concert.

d. From the data in the preceding tabulation, the grading volumes can be obtained as follows:

$$V_s = I_v P_s$$

where

I_v = volume index from tabulation in subparagraph a above.

P_s = proportion of total volume composed of soil = $\frac{100 - V_i}{100}$, where V_i = relative rock volume from tabulation in subparagraph c above.

Then

$$V_s = \frac{I_v (100 - V_i)}{100}$$

and

$$V_r = \frac{I_v V_i}{100}$$

where V_s and V_r are volume of soil and volume of rock, respectively.

Difficulty of Providing Drainage

32. In general, the relative difficulty of providing adequate drainage is controlled by the slopes that are available to carry off water, and by the relative freedom of internal drainage of the soil. The steeper the characteristic slope of a terrain, usually the better the external drainage, and the coarser the texture, the better the internal drainage. A summary of the relative influence of these factors acting in concert is tabulated below.

Material	Relative Difficulty of Providing Drainage (d) < 2% Characteristic Slope	2% to 10% Characteristic Slope	10% to 30% Characteristic Slope	> 30% Characteristic Slope
Clay	1.0	0.8	0.7	0.6
Silt	0.9	0.7	0.5	0.4
Laterite	0.7	0.5	0.4	0.3
Sand, rock	0.3	0.1	0.0	0.0

The laterites and lateritic soils are somewhat anomalous; although composed predominantly of silt- and clay-sized materials, they commonly have good internal drainage characteristics.

Difficulty of Clearing Vegetation

33. A major item of construction effort is that involved in clearing the land of vegetation prior to grading. The enormous variation in vegetation types and the lack of detailed knowledge concerning the relative importance of various aspects of this task make it difficult to establish consistent quantitative measures. Six very broad vegetation categories were selected, primarily on the basis of density and size of woody vegetation. The difficulty of clearing vegetation is also related to the roughness of the ground on which the vegetation occurs and to the nature of soils in which the plants are growing. In the following tabulation, vegetation categories and characteristic slopes are given with the appropriate difficulty index.

Vegetation Type	Vegetation Clearing Difficulty Index (C) < 2% Characteristic Slope	2% to 10% Characteristic Slope	10% to 30% Characteristic Slope	> 30% Characteristic Slope
Barren	0	0	0	0
Grass, or large cultivated fields	0.10	0.11	0.12	0.13
Savanna, or small cultivated fields	0.50	0.55	0.60	0.65
Woodland, or forest with scattered fields	2.00	2.20	2.40	2.60
Scrub	5.00	5.50	6.00	6.50
Forest	6.00	6.60	7.20	7.80

Literature Search

34. A literature search was initiated to see what data were available that would assist in revising the index values. This search included appropriate TM's, construction publications, engineer equipment manufacturers' handbooks, and unpublished information concerning the effect of terrain on horizontal construction. The publications reviewed are included in the Bibliography.

35. The publications reviewed considered all the terrain factors included in the EHCEM although in practically all instances the terms used were not compatible with the EHCEM terms. Some of the publications dealt in specific terms (i.e. bucket size, density of material, effective grade, rolling resistance, grade resistance, etc.) which were difficult to correlate with the requirements of the EHCEM within the scope of this study. One publication (Royster) presented an excavation index ranging from 1 to 10 base degrees of excavation difficulty of

materials related to scraped, bladed, ripped, and blasted. The description of soils varied widely, which included such terms as topsoil, dirt, earth, etc. The DA Pamphlet 525-6 concerning land clearing has a lot of detailed data; however, the terms used were not easily correlatable to the input requirements for the EHCEM.

36. The most applicable data source located was an unpublished study performed at WES in 1967 entitled "Construction Effort Relations for VTOL Landing Modules." The model used to determine construction effort is the same as the EHCEM except for the difficulty of providing drainage. The terrain input used to determine the index values involved similar parameters but not in identical terms; however, most of the data were in such a form that it could be utilized to generate the appropriate values for the index input requirements. Therefore, this reference was selected as the principal source used to revise the index values for the EHCEM.

Terrain Effects on Construction Activities

37. The relationships between the terrain factors and the construction activities were presented in the extract from TM 5-366 (paragraphs 31-33 herein). Revisions to some of the terrain factors (vegetation descriptors, addition of a soil thickness class, and expansion of the soil types) required that these descriptors be incorporated into the index tables (difficulty and volume) for input to the EHCEM. While the above-mentioned revisions were required, it was deemed desirable that all the existing index (volume and difficulty) values be examined in conjunction with the data obtained from the literature survey to identify other revisions that could be made to improve the existing index values. This evaluation process is not to be considered exhaustive. The procedures used to convert the data generated by the construction effort study for VTOL modules are discussed in subsequent paragraphs.

Volume moved

38. As previously discussed, the EHCEM is dependent upon volume of soil moved (V_s), the volume of rock moved (V_r), and the difficulty in moving these materials. The values of V_s and V_r are relative indicators for the effort required to move any volume of earth under the respective terrain condition and not the specific volume of earth to be moved for a given facility. This latter correlation is accomplished at the time values for the grading constant (k_g) are calculated.

39. The volume moved in the EHCEM is involved with the volume index (I_V), grading difficulty index (D), and relative rock volume (V_i) in percent which are affected by slope, soil type, and slope-soil thickness, respectively. Each of the above factors is discussed in the following paragraphs.

40. Volume index. The CE study for VTOL modules had developed a series of curves for module diameters with slope as the ordinate and I_V as the abscissa. The maximum diameter was 320 ft. For this study a diameter of 500 ft was chosen and a curve was developed through a regression analysis of the family of curves (see Figure 5). I_V values for the slope classes were selected from the new curve:

Slope Class (%)	Volume Index, I_V
< 2	0.5
2 - 10	1.5
>10 - 30	5.3
>30	7.8

41. The associated relief used prior to the study has been eliminated because no data were generated for this association and because of the inability to determine in specific terms how this association was generated.

42. Grading difficulty. The grading difficulty generated by the VTOL study was divided into soil and rock. For soils, two curves were generated, one for wet conditions and the other for dry conditions, with soil type as the ordinate and grading difficulty index as the abscissa. The soil types were identified in categories of sand, silt, clay, and

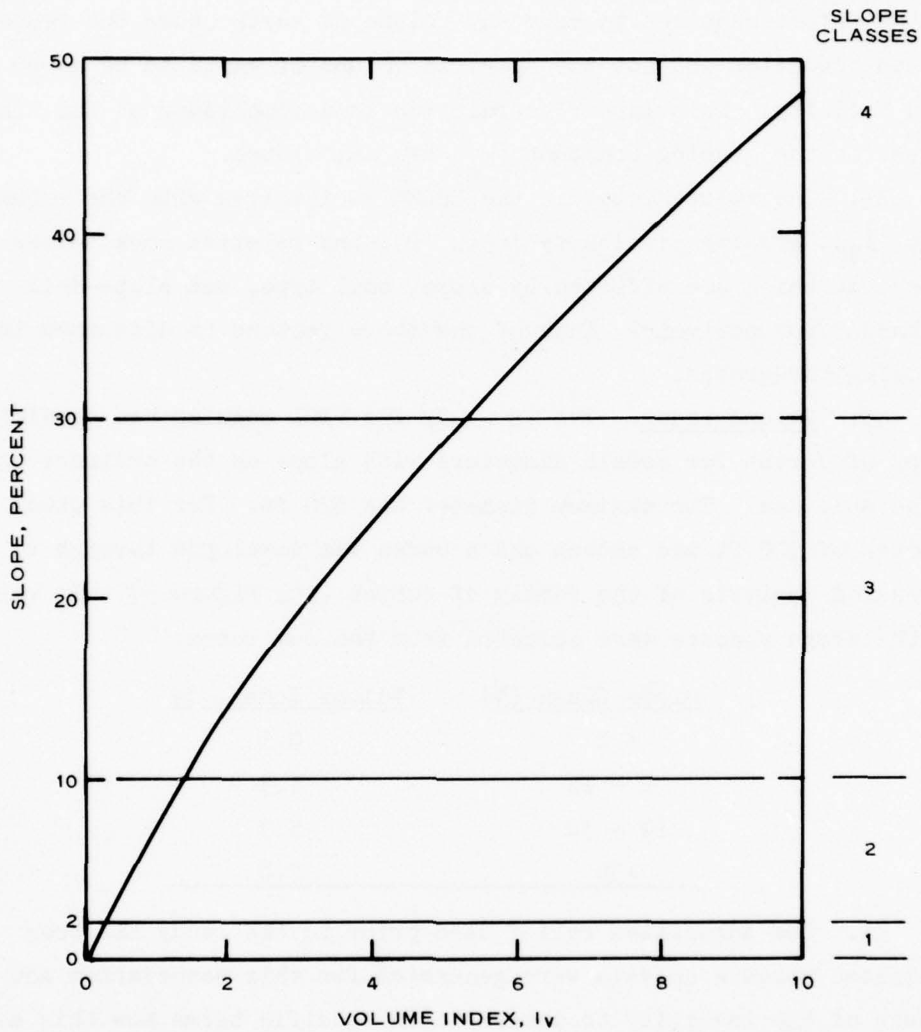


Figure 5. Volume of material moved by grading

organic (peat). The curves were not changed. To determine the grading difficulty for the soil classes identified for this study, the following changes were made to the graph from the VTOL study and are presented on Figure 6:

a. The sand line was identified as SP, SW, GP, GW, GM, and GC and where this line intersected the curves (wet and dry), these were the D_s values of clean sand and gravels.

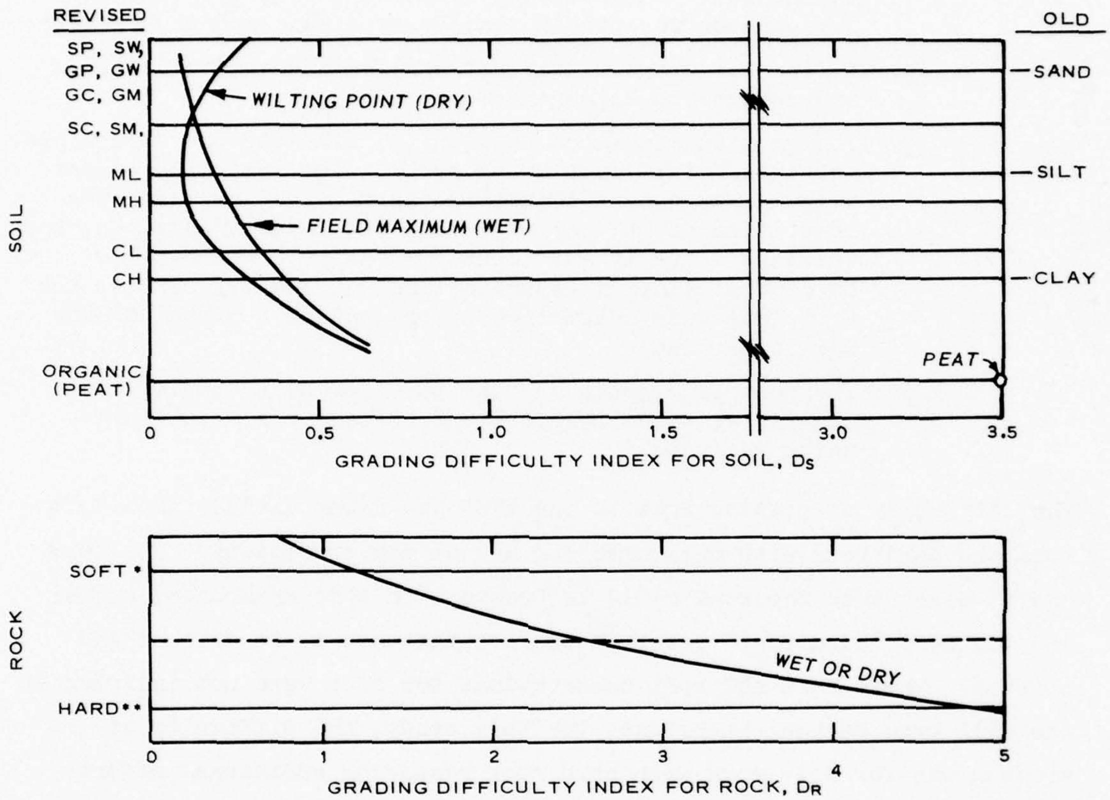
b. A line was drawn midway between the sand and silt lines and designated as SM and SC.

c. The vertical distance between the silt and clay lines was subdivided into four equal parts. The silt line on the original graph was identified as ML, the next line was identified as MH, the clay line was identified as CH, and the line above it was identified as CL. Where these horizontal lines intersected the wet and dry curves, the D_s values were determined by projecting a normal to the soil type line.

d. The peat or organic was the same for both studies; therefore, no correlation was necessary and the same value was used.

The difficulty of grading rock in the VTOL study was divided into soft rock and hard rock with one curve for wet or dry conditions. The term "soft" meant that the rock could be broken with a dozer-mounted ripper and the term "hard rock" referred to rock that had to be drilled and blasted. These hard and soft connotations for rock were not included in the soil type factor; therefore, for this study, the difficulty of grading was for soft rock with hard rock requiring additional effort that is to be identified separately. The resulting values for grading difficulty by soil type and rock are as follows:

Material	Grading Difficulty Index (D)	
	Dry	Wet
GW, GP, GC, GM	0.20	0.10
SW, SP	0.20	0.10
SC, SM	0.12	0.15
ML	0.10	0.20
MH	0.12	0.25
CL	0.20	0.33
CH	0.30	0.40
Organic (peat)	3.50	3.50
Rock (rippable)	1.20	1.20



* ROCK THAT CAN BE BROKEN WITH A DOZER-MOUNTED RIPPER, INCLUDING HARD LATERITE

** ROCK THAT MUST BE DRILLED AND BLASTED

Figure 6. Grading difficulty index

Relative volume of rock (V_i)

43. The VTOL study generated a series of relationships between characteristic slope and soil thickness, resulting in relative rock volume (V_i) for each module diameter. For example, the ordinate was the soil thickness and the V_i was the abscissa. Straight lines representing specific slopes of 2, 5, 10, 20, 30, and 40 percent were drawn on the graph. Data for this study were generated by running a regression analysis of the slopes for each module and plotting a new graph for a module of 500 ft. The resulting values of V_i for ranges of soil thickness up to 25 ft and characteristic slope up to 40 percent were determined from the graph shown in Figure 7 and are presented below:

Relative Rock Volume (V_i)

Soil Thickness ft	Characteristic Slopes (%)			
	< 2%	2-10%	10-30%	>30%
< 2	66	95	98	99
2-10	0	68	90	95
>10-20	0	35	80	86
>20	0	18	72	78

Relative difficulty of providing drainage (d)

44. Data used to revise the d for this study came from a graph generated by the VTOL study where the soil types were identified on the ordinate and the d values were positioned along the abscissa with curves representing slopes of 2, 10, 20, 30, 40, and 50 percent. The soil types were in terms of sand, silt, and clay. For this graph to be utilized, the broad soil terms had to be converted to the USCS categories used as mapping classes in the soil type map (see Figure 8).

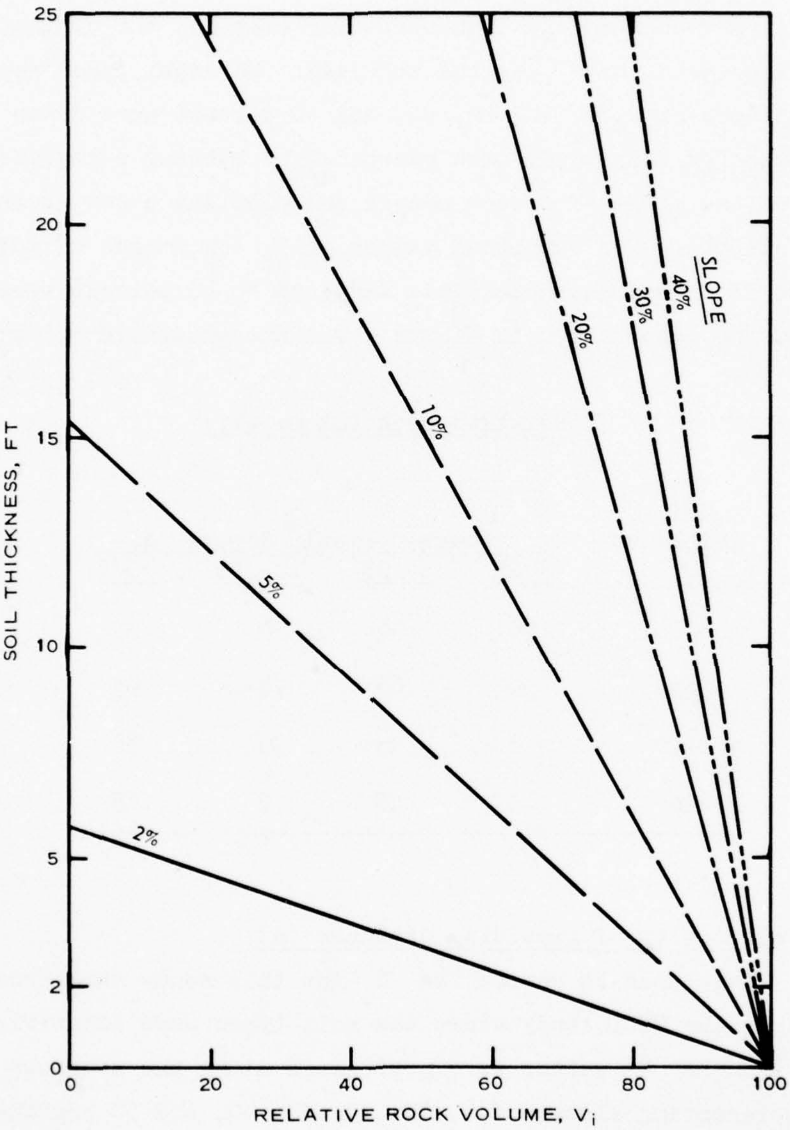


Figure 7. Relative rock volume

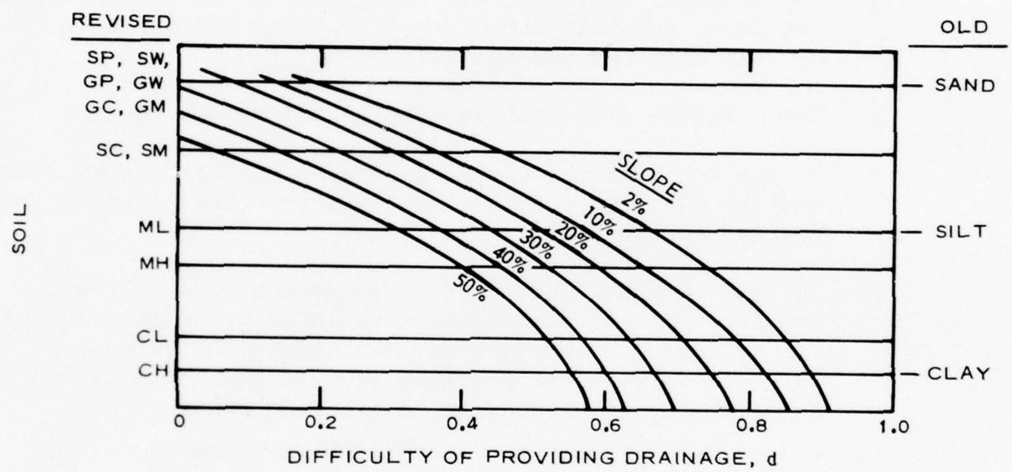


Figure 8. Drainage index

45. The soil type conversions were made as follows:

a. The original graph had only three horizontal lines representing the sand, silt, and clay soils. For this study, lines were drawn midway between sand and silt lines and midway between the silt and clay lines. These lines were assumed to divide the graph into the three soil types.

b. The sand categories were assumed to include the GP, GW, GM, GC, SP, and SW.

c. The line midway between the sand and silt lines was designated as the SM and SC.

d. The original silt line was designated as ML. The MH line was drawn one-half the distance between the dividing line of silt and clay and the silt or ML line.

e. The original clay line was designated as the CH line.

f. A line one-half the distance between the clay or CH line and the dividing line between silt and clay was drawn and designated the CL line.

g. No data were available for organics and rock. It was assumed that d for organics would be 0.1 more than that for CH and 0.1 was added for each characteristic slope. The rock values from previous studies and those listed in paragraph 32 were used for d in this study.

46. The values for difficulty of providing drainage identified for this study are presented below:

	Relative Difficulty of Providing Drainage (d) for Indicated Characteristic Slopes			
Material	< 2%	2-10%	10-30%	>30%
GW, GP, GC, GM, SW, SP	0.20	0.15	0.00	0.00
SC, SM	0.46	0.37	0.24	0.15
ML	0.66	0.57	0.44	0.37
MH	0.75	0.66	0.52	0.45
CL	0.85	0.78	0.63	0.57
CH	0.89	0.83	0.67	0.61
Organics	0.99	0.93	0.77	0.71
Rock	0.30	0.10	0.00	0.00

Difficulty of clearing vegetation

47. The VTOL study had generated a series of graphs, each representing the relationship of basal area, slope, and difficulty of clearing vegetation for five module diameters. The ordinate of the graph represented basal area in m^2 per 10,000 m^2 with horizontal lines drawn dividing the graph into the six vegetation mapping classes. The abscissa had values from 0-12 for the difficulty of clearing vegetation and curves representing specific slopes of 2, 5, 10, 20, and 40 percent. Data for this study were generated by running a regression analysis of the slope curves for each module and plotting a new graph for a 500-ft module. The basal area from the vegetation legend which was in English units was computed for each class and converted to metric units and vegetation class limits were drawn on the graph. The resulting values needed for vegetation clearing difficulty index were extracted from the graph (see Figure 9) and are presented below:

Vegetation Class	Vegetation Clearing Difficulty Index (C) for Indicated Characteristic Slopes			
	< 2%	2-10%	10-30%	>30%
1	0	0	0	0
2	0.20	0.25	0.30	0.35
3	1.40	1.60	2.0	2.20
4	3.80	4.10	4.50	5.0
5	5.40	5.80	6.5	7.0
6	8.30	8.50	10.00	10.70*

* Extrapolated.

Remarks

48. The preceding paragraphs identified the volume and difficulty indexes used originally as input to the EHCEM and those generated during this study. The original volume and difficulty index values are compared with the revised values on Figures 10-13. A summary of the

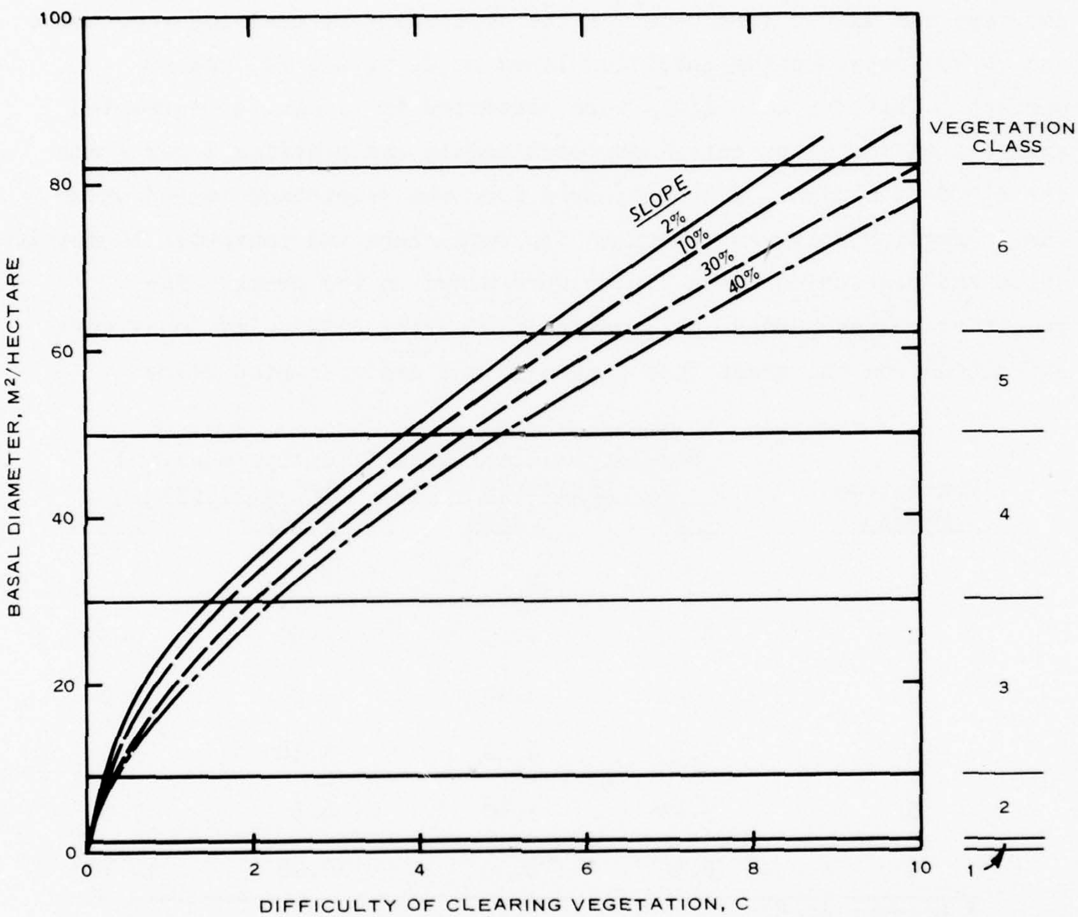


Figure 9. Vegetation clearing index

variations between the revised and original values is presented in the following paragraphs.

Volume index, I_V

49. The revised indexes in all cases showed a decrease except for an increase for the 10-30 percent class.

Relative rock volume, V_i

50. The revised indexes were larger than the original values for soil < 2 ft thick for all slope classes and for all soil thickness classes where slopes are greater than 2 percent. The remaining combinations of soils > 2 ft thick and slope less than 2 percent have resulted in the original V_i being larger than the revised values, except for the soil thickness > 20 ft and a slope < 2 percent where the values are the same.

Grading difficulty index, D

51. The increase in soil type classes mapped in this study from the original map classes made comparison of the original values with the revised D values not straightforward. Sand was compared with three classes (GW, GP, GC, GM; SW, SP; and SC, SM) of the revised soils and the original D was lower in the dry state than the revised D. In the wet state the original D was the same as the revised D except in one case where the revised D was larger. Silt from the original study was compared with ML and MH in this study. The D for silt and ML was the same in both wet and dry conditions. The revised wet and dry D's for MH were larger than the original D for silt. Clay from the original study was compared with CL and CH in this study. The D's for clay and CL were the same in the wet condition but differed in the dry condition. The revised wet and dry D's for CH were larger than the original D for clay. Laterite was not compared with any soil type in this study and organic was not compared with any soil type in the original study. The D's for the rock or hard laterite from the original study were the same as those for rock (rippable) in this study.

Relative difficulty of providing drainage, d

52. The comparisons of the original soil types and the revised soil classes were accomplished the same for d as they were for grading

Slope Category, %	Volume Index, I_v Original	Volume Index, I_v Revised	Associated Relief, ft Original
0 to 2	1	0.5	< 100
> 2 to 10	2	1.5	100 to 500
>10 to 30	4	5.3	501 to 2000
> 30	8	7.8	> 2000

Relative Rock Volume (V_i)

Soil Thickness ft		Characteristic Slope (%)							
		0 to 2		>2 to 10		> 10 to 30		>30	
Orig	Rev	Orig	Rev	Orig	Rev	Orig	Rev	Orig	Rev
< 2	< 2	20†	66	40	95	60	98	90	99
	2 to 10		0		68		90		95
2 to 20		10		20		50		80	
	>10 to 20		0		35		80		86
> 20	> 20	0	0	10	18	30	72	60	78

† Value indicates that 20% of the graded volume will probably be rock in those areas where the soil is less than 2 ft thick and the characteristic slope is less than 2%.

Figure 10. Comparison of original and revised volume index factors

Material		Grading Difficulty Index, D			
		Dry		Wet	
Orig	Rev	Orig	Rev	Orig	Rev
	GW, GP, GC, GM		0.20		0.10
Sand	SW, SP	0.10		0.10	
	SC, SM		0.12		0.15
	ML		0.10		0.20
Silt		0.10		0.20	
	MH		0.12		0.25
	CL		0.20		0.33
Clay		0.20		0.30	
	CH		0.30		0.40
Laterite (soft)	NI	0.20		0.30	
NI	Organic (Peat)		3.50		3.50
Rock or laterite (hard)	Rock, rippable	1.50	1.20	1.50	1.20

NI - not identified.

Figure 11. Comparison of original and revised difficulty of grading index values

Material		Relative Difficulty of Providing Drainage d, for Indicated Characteristic Slopes							
		< 2%		2 to 10%		10 to 30%		> 30%	
Orig	Rev	Orig	Rev	Orig	Rev	Orig	Rev	Orig	Rev
	CL		0.85		0.78		0.63		0.57
Clay		1.0		0.8		0.7		0.6	
	CH		0.89		0.83		0.67		0.61
	ML		0.66		0.57		0.44		0.37
Silt		0.9		0.7		0.5		0.4	
	MH		0.75		0.66		0.52		0.45
Laterite		0.7		0.5		0.4		0.3	
	GW, GP GC, GM, SW, SP		0.20		0.15		0.0		0.0
Sand		0.3		0.1		0.0		0.0	
	SC, SM		0.46		0.37		0.24		0.15
	Peat		0.99		0.93		0.77		0.71
Rock	Rock	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0

Figure 12. Comparison of original and revised difficulty of providing drainage factors

Vegetation Type		Vegetation Clearing Difficulty Index (C) for Indicated Characteristic Slopes							
		< 2%		2 to 10%		10 to 30%		> 30%	
Description	Class	Orig	Rev	Orig	Rev	Orig	Rev	Orig	Rev
Barren	1	0	0	0	0	0	0	0	0
Grass, or large cultivated fields	2	0.10	0.20	0.11	0.25	0.12	0.30	0.13	0.35
Savanna, or small cultivated fields	3	0.50	1.40	0.55	1.60	0.60	2.00	0.65	2.20
Woodland, or forest with scattered fields	4	2.00	3.80	2.20	4.10	2.40	4.50	2.60	5.00
Scrub	5	5.00	5.40	5.50	5.80	6.00	6.50	6.50	7.00
Forest	6	6.00	8.30	6.60	8.50	7.20	10.00	7.80	10.70

Figure 13. Comparison of original and revised vegetation clearing difficulty index factors

difficulty D . The original values, when compared with the revised values for the various slope categories, varied from the same to smaller or larger. Only the rock category values were not changed.

Vegetation clearing difficulty index, C

53. The revised C values were larger than the original values in all instances except under the barren category which was the same as the vegetation map class 1.

PART V: CONSTRUCTION EFFORT FOR CLIMATIC ZONES

54. The EHCEM was designed to take into consideration not only the volume and difficulty indexes which this report has been devoted to but also the constants which are based on aircraft load, tire pressure and runway length. From these data a prediction of effort in battalion-days to construct a specific type of airfield is generated. As an example of construction efforts, a medium lift support area airfield has been selected for calculations using the original data (indexes and terrain) and the revised data (generated by this study). A typical layout of this airfield is shown on Figure 14. The k values for a subgrade of 10-20 CBR were extracted from Table XVIII-1 of TM 5-366. These values are $k_g = 13$, $k_d = 1.3$, and $k_c = 1.6$. It should be noted that equations in TM 5-366 contain precalculated values for scenario coefficients that are based on assumed typical operational data ranges. An engineer construction battalion was assigned the project which has an F value of 0.75. The EHCEM for the constants and the engineer battalion is shown below:

$$C_e = \{13 (V_s D_s + V_r D_r) + 1.3d + 1.6C\} 0.75$$

The construction efforts for the selected factor complexes are presented in Tables 1-4 for factor complexes in the desert, frigid, temperate, and tropic climatic zones, respectively. The C_e was computed using the old and revised index values. The terrain factor complexes selected for computation of C_e were the median, upper quartile, and maximum for each climatic zone (see Tables 5-8). Computations of the C_e minimum and lower quartile were not made because of their low occurrence and areal occupancy.

55. The resulting C_e's for the factor complexes are self-explanatory. However, a few comments are in order. In most instances the C_e's using the revised indexes are larger than those computed when the old indexes are used. An obvious result of the C_e is that whenever

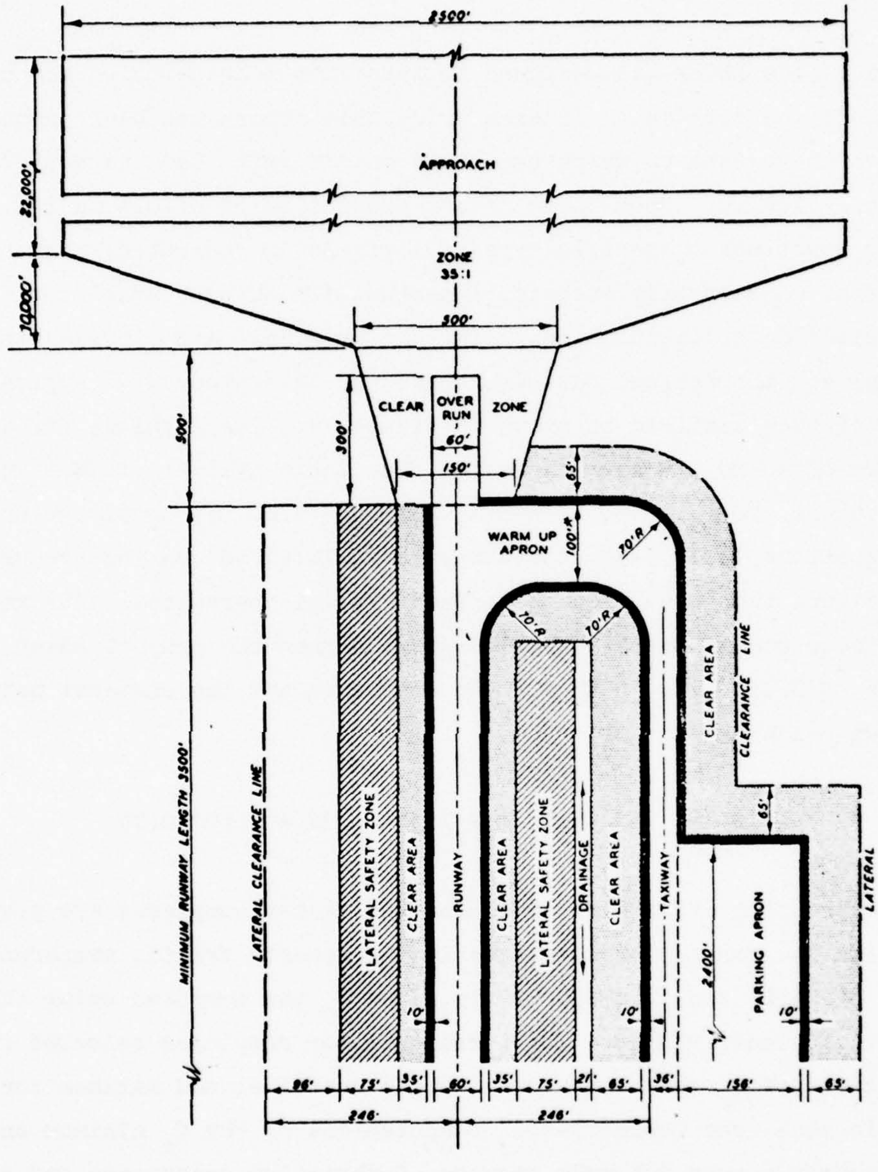


Figure 14. Typical layout of medium lift support area airfield

a high slope (map classes 3 and 4) is combined with a shallow soil thickness (map class 1), the C_e requirement exceeds 60 days and reaches up to 110 days. In contrast, where slope class 1 is combined with a soil thickness class 4, only a few days are required to construct the specified airfield. Map classes are identified in Figure 3.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

56. On the basis of this study, the following conclusions were drawn:

<u>a</u>. The introduction of curves makes the selection of index and volume values more flexible than the previous rigid values identified on tables.

<u>b</u>. The expansion of factor classes for soil types and soil thicknesses, and identifying stem spacing and stem diameter in the vegetation, has made these factors more definitive.

<u>c</u>. Additional terrain or environmental factors should be considered for inclusion as input to the EHCEM. These factors should include (as a minimum) altitude (which affects the performance of equipment) and frozen soils in the applicable climatic zone.

<u>d</u>. Only very limited validation has been performed on the EHCEM to determine the reliability of the output and a program should be implemented to validate the EHCEM.

<u>e</u>. Terrain conditions are not respectors of climatic zones because of the duplication of factor complexes in various zones.

Recommendations

57. This study has resulted in the following recommendations:

<u>a</u>. A study should be initiated to validate the EHCEM. This study should be a series of field exercises and would not only validate the terrain effects on horizontal construction but also the F value for the type of battalion employed.

<u>b</u>. A study should be conducted to determine the effects of frozen ground and altitude on the horizontal construction and to incorporate these factors into the input to the EHCEM.

c. Class ranges of slope and soil thickness should be re-examined to determine if additional changes are required and what the impact is on the output of the EHCEM. If this is done, then determine if the acquisition of these additional data requirements are warranted in terms of improved output weighed against time and cost.

d. Additional countries should be mapped and the factor complexes should be analyzed to determine what changes occur in the occurrence and frequency of factor complexes in the data base generated by this study.

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TABLE 1

Analysis of Terrain Factor Complexes; Desert Zone

Number of Factor Complexes: 260 Total Area: 5,254,315 km^2 Total Patches (TP): 4,397

Rating Position	Frequency: Factor Complex	Frequency: Number Patches	Frequency: % TP	Areal Occupancy: Factor Complex	Areal Occupancy: Area, km^2	Areal Occupancy: % Occupancy	Area-Frequency Index: Factor Complex	Area-Frequency Index: I_T
	1116	1	0.0229	2422	1	0.0000	2422	0.4356×10^{-8}
Minimum	1222	1	0.0229	3224	2	0.0000	3244	0.1742×10^{-7}
	1224	1	0.0229	1224	5	0.0001	1224	0.2178×10^{-7}
	3144	2	0.0458	4546	111	0.0021	3921	0.8407×10^{-6}
Lower Quartile	3146	2	0.0458	3436	112	0.0021	1212	0.8625×10^{-6}
	3224	2	0.0458	2545	115	0.0022	2222	0.9409×10^{-6}
	2121	6	0.1373	4642	641	0.0122	4244	0.1464×10^{-4}
Median	2314	6	0.1373	2115	642	0.0122	4431	0.1472×10^{-4}
	2446	6	0.1373	3442	653	0.0124	3212	0.1490×10^{-4}
	3442	17	0.3891	4641	4,093	0.0779	4311	0.2740×10^{-3}
Upper Quartile	1142	18	0.4120	1311	4,309	0.0820	1244	0.2745×10^{-3}
	4412	18	0.4120	1245	4,694	0.0893	3414	0.2824×10^{-3}
	1341	159	3.639	4911	422,271	8.0367	4916	0.1890
Maximum	2341	164	3.754	4111	435,703	8.2923	1241	0.2013
	4911	254	5.814	1241	471,432	8.9723	4911	0.4672

TABLE 2

Analysis of Terrain Factor Complexes; Frigid Zone

Number of Factor Complexes: 89 Total Area: 2,664,796 Total Patches (TP): 1,044

	Frequency			Areal Occupancy			Area-Frequency Index	
Rating Position	Factor Complex	Number Patches	% TP	Factor Complex	Area, km^2	% Occupancy	Factor Complex	I_T
	1135	1	0.0958	2412	22	0.0008	2412	0.7908×10^{-6}
Minimum	1225	1	0.0958	2245	32	0.0020	2245	0.1150×10^{-5}
	1346	1	0.0958	2144	33	0.0033	2144	0.1186×10^{-5}
	3524	1	0.0958	1542	418	0.0157	1543	0.2746×10^{-4}
Lower Quartile	3812	1	0.0958	1216	580	0.0218	3516	0.2976×10^{-4}
	3816	1	0.0958	1523	728	0.0273	2523	0.3102×10^{-4}
	3316	3	0.2874	3344	3,113	1.429	4214	0.4244×10^{-3}
Median	3844	3	0.2874	3315	3,373	1.556	3212	0.4570×10^{-3}
	1835	4	0.3831	2344	3,453	1.685	1315	0.4620×10^{-3}
	2835	11	1.054	2315	10,206	5.477	2235	0.3474×10^{-2}
Upper Quartile	1315	14	1.341	2342	10,805	5.883	3214	0.4411×10^{-2}
	2325	16	1.533	2446	11,086	6.299	2836	0.4422×10^{-2}
	2342	59	5.56	2346	286,675	10.78	2346	0.1958
Maximum	2314	81	7.78	1842	618,018	23.25	1845	0.2377
	1842	88	8.45	1846	734,702	27.63	1842	1.955

TABLE 3

Analysis of Terrain Factor Complexes; Temperate Zone

Number of Factor Complexes: 206 Total Area: 998,081 km^2 Total Patches (TP): 6,962

	Frequency			Areal Occupancy			Area-Frequency Index	
Rating Position	Factor Complex	Number Patches	% TP	Factor Complex	Area, km^2	% Occupancy	Factor Complex	I_T
	1142	1	0.0283	1612	1	0.0001	1612	0.1439×10^{-7}
Minimum	1146	1	0.0283	1414	4	0.0004	1414	0.5757×10^{-7}
	1232	1	0.0283	4434	4	0.0004	4434	0.5757×10^{-7}
	2742	3	0.0851	2414	75	0.0075	3445	0.2849×10^{-5}
Lower Quartile	2826	3	0.0851	2822	77	0.0075	4446	0.2893×10^{-5}
	3722	3	0.0851	2336	77	0.0077	3522	0.3195×10^{-5}
	2746	7	0.1987	3446	835	0.0837	3446	0.1442×10^{-3}
Median	2822	7	0.1987	1642	837	0.0839	4432	0.1456×10^{-3}
	3345	7	0.1987	3332	852	0.0854	2332	0.1511×10^{-3}
	3726	21	0.5961	3532	3,703	0.3710	3422	0.2621×10^{-2}
Upper Quartile	3332	22	0.62	2322	3,716	0.3723	3324	0.2679×10^{-2}
	3534	22	0.62	1444	3,811	0.3818	2344	0.2764×10^{-2}
	2312	198	2.83	4312	45,437	4.56	2312	0.1155
Maximum	1342	213	3.05	3312	102,215	10.25	2432	0.1487
	3312	333	4.77	2432	103,309	10.36	3312	0.4898

TABLE 4

Analysis of Terrain Factor Complexes; Tropic Zone

Number of Factor Complexes: 198 Total Area: 1,664,317 Total Patches (TP): 3,523

Rating Position	Frequency: Factor Complex	Frequency: Number Patches	Frequency: % TP	Areal Occupancy: Factor Complex	Areal Occupancy: Area, km^2	Areal Occupancy: % Occupancy	Area-Frequency Index: Factor Complex	Area-Frequency Index: I_T
	1142	1	0.0283	2316	6	0.0004	2316	0.1023×10^{-6}
Minimum	1146	1	0.0283	4644	7	0.0004	4644	0.1194×10^{-6}
	1234	1	0.0283	1826	8	0.0005	1826	0.1364×10^{-6}
	4736	2	0.0567	4314	213	0.0128	4332	0.1059×10^{-4}
Lower Quartile	1246	3	0.0851	1643	224	0.0135	2824	0.1098×10^{-4}
	1626	3	0.0851	2732	234	0.0141	1822	0.1293×10^{-4}
	3446	6	0.1703	4226	1,081	0.0650	2444	0.1162×10^{-3}
Median	4726	6	0.1703	2444	1,136	0.0683	2646	0.1321×10^{-3}
	1722	7	0.1987	3736	1,146	0.0689	4346	0.1335×10^{-3}
	2642	18	0.5109	3535	3,240	0.1947	1326	0.1009×10^{-2}
Upper Quartile	3343	18	0.5109	2326	3,431	0.2062	1126	0.1101×10^{-2}
	4532	18	0.5109	3222	3,579	0.2150	2746	0.1130×10^{-2}
	3336	136	3.85	2346	84,583	5.082	1336	0.1109
Maximum	1332	144	4.07	1243	168,421	10.119	1342	0.1189
	1336	149	4.21	2343	223,239	13.406	2336	0.1428

TABLE 5

HORIZONTAL CONSTRUCTION EFFORT (C_e) IN SELECTED TERRAIN CONDITIONS;* DESERT ZONE

Type of Airfield: Medium Lift Support Area

Rating Position	Frequency: Factor Complex	Frequency: C_e,** Volume and Difficulty Indexes Applied: Old	Frequency: Revised	Areal Occupancy: Factor Complex	Areal Occupancy: C_e, Volume and Difficulty Indexes Applied: Old	Areal Occupancy: Revised	Area-Frequency I_T: Factor Complex	Area-Frequency I_T: C_e, Volume and Difficulty Indexes Applied: Old	Area-Frequency I_T: Revised
	2121	8	14	4642	78	78	4244	77	81
Median	2314	18	23	2115	20	24	4431	98	82
	2446	16	17	3442	24	49	3212	37	62
	3442	24	49	4641	108	77	4311	108	91
Upper quartile	1142	2	2	1311	6	5	1244	4	6
	4412	108	92	1245	8	8	3414	42	67
	4911	117	92	1211	4	5	4911	117	92
Maximum	2341	7	5	4111	107	91	1241	2	2
	1341	3	2	4911	117	92	4916	127	105

* Factor complexes were extracted from Tables 1-3, Volume II (C), Factor Complex Data for Climatic Zones (U), for construction computations.

** C_e is construction effort in battalion-days.

TABLE 5

HORIZONTAL CONSTRUCTION EFFORT (C_e) IN SELECTED TERRAIN CONDITIONS;* DESERT ZONE

Type of Airfield: Medium Lift Support Area

Rating Position	Frequency			Areal Occupancy			Area-Frequency I_T		
	Factor Complex	C_e,** Volume and Difficulty Indexes Applied: Old	Revised	Factor Complex	C_e, Volume and Difficulty Indexes Applied: Old	Revised	Factor Complex	C_e, Volume and Difficulty Indexes Applied: Old	Revised
Median	2121	8	14	4642	78	78	4244	77	81
	2314	18	23	2115	20	24	4431	98	82
	2446	16	17	3442	24	49	3212	37	62
Upper quartile	3442	24	49	4641	108	77	4311	108	91
	1142	2	2	1311	6	5	1244	4	6
	4412	108	92	1245	8	8	3414	42	67
Maximum	4911	117	92	1211	4	5	4911	117	92
	2341	7	5	4111	107	91	1241	2	2
	1341	3	2	4911	117	92	4916	127	105

* Factor complexes were extracted from Tables 1-3, Volume II (C), Factor Complex Data for Climatic Zones (U), for construction computations.

** C_e is construction effort in battalion-days.

TABLE 6

HORIZONTAL CONSTRUCTION EFFORT (C_e) IN SELECTED TERRAIN CONDITIONS;* FRIGID ZONE

Type of Airfield: Medium Lift Support Area

	Frequency			Areal Occupancy			Area-Frequency I_T		
		C_e,** Volume and Difficulty Indexes Applied			C_e, Volume and Difficulty Indexes Applied			C_e, Volume and Difficulty Indexes Applied	
Rating Position	Factor Complex	Old	Revised	Factor Complex	Old	Revised	Factor Complex	Old	Revised
Median	3316	48	74	3344	27	53	4214	110	97
	3844	21	102	3315	46	69	3212	37	62
	1835	8	25	2344	10	10	1315	12	11
Upper quartile	2835	13	48	2315	22	25	2235	15	16
	1315	12	11	2342	8	6	3214	40	67
	2325	17	20	2446	16	17	2836	14	51
Maximum	1842	1	19	1846	8	29	1842	1	19
	2314	18	23	1842	1	19	1845	6	25
	2342	8	6	2346	15	16	2346	15	16

* Factor complexes were extracted from Tables 4-6, Volume II (C) Factor Complex Data for Climatic Zones (U), for construction computations.

** C_e is construction effort in battalion-days.

TABLE 7

HORIZONTAL CONSTRUCTION EFFORT (C_e) IN SELECTED TERRAIN CONDITIONS;* TEMPERATE ZONE

Type of Airfield: Medium Lift Support Area

	Frequency			Areal Occupancy			Area-Frequency I_T		
		Ce,** Volume and Difficulty Indexes Applied			Ce, Volume and Difficulty Indexes Applied			Ce, Volume and Difficulty Indexes Applied	
Rating Position	Factor Complex	Old	Revised	Factor Complex	Old	Revised	Factor Complex	Old	Revised
	2746	16	16	3446	33	61	3446	33	61
Median	2822	6	30	1642	4	3	4432	98	82
	3345	31	55	3332	34	52	2332	10	8
Upper	3726	41	69	3532	32	52	3422	34	58
quartile	3332	34	52	2322	10	14	3324	37	63
	3534	35	57	1444	6	7	2344	10	10
	3312	39	62	2432	10	10	3312	39	62
Maximum	1342	3	2	3312	39	62	2432	9	10
	2312	15	18	4312	108	91	2312	15	18

* Factor complexes were extracted from Tables 7-9, Volume II (C), Factor Complex Data for for Climatic Zones (U), for construction computations.

** C_e is construction effort in battalion-days.

TABLE 8

HORIZONTAL CONSTRUCTION EFFORT (C_e) IN SELECTED TERRAIN CONDITIONS;* TROPIC ZONE

Type of Airfield: Medium Lift Support Area

Rating Position	Frequency: Factor Complex	Frequency: C_e,** Volume and Difficulty Indexes Applied: Old	Frequency: C_e,** Volume and Difficulty Indexes Applied: Revised	Areal Occupancy: Factor Complex	Areal Occupancy: C_e, Volume and Difficulty Indexes Applied: Old	Areal Occupancy: C_e, Volume and Difficulty Indexes Applied: Revised	Area-Frequency I_T: Factor Complex	Area-Frequency I_T: C_e, Volume and Difficulty Indexes Applied: Old	Area-Frequency I_T: C_e, Volume and Difficulty Indexes Applied: Revised
Median	3446	33	61	4226	105	101	2444	10	12
	4726	105	101	2444	10	12	2646	16	18
	1722	4	2	3736	30	64	4346	87	87
Upper quartile	2642	8	7	3535	28	59	1326	12	11
	3343	25	50	2326	18	24	1126	10	12
	4532	98	81	3222	32	58	2746	14	16
Maximum	1336	12	11	2343	8	7	2336	18	18
	1332	5	2	1243	2	3	1342	3	2
	3336	43	64	2346	15	16	1336	12	11

* Factor complexes were extracted from Tables 10-12, Volume II (C), Factor Complex Data for Climatic Zones (U), for construction computations.

** C_e is construction effort in battalion-days.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Shamburger, John H
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